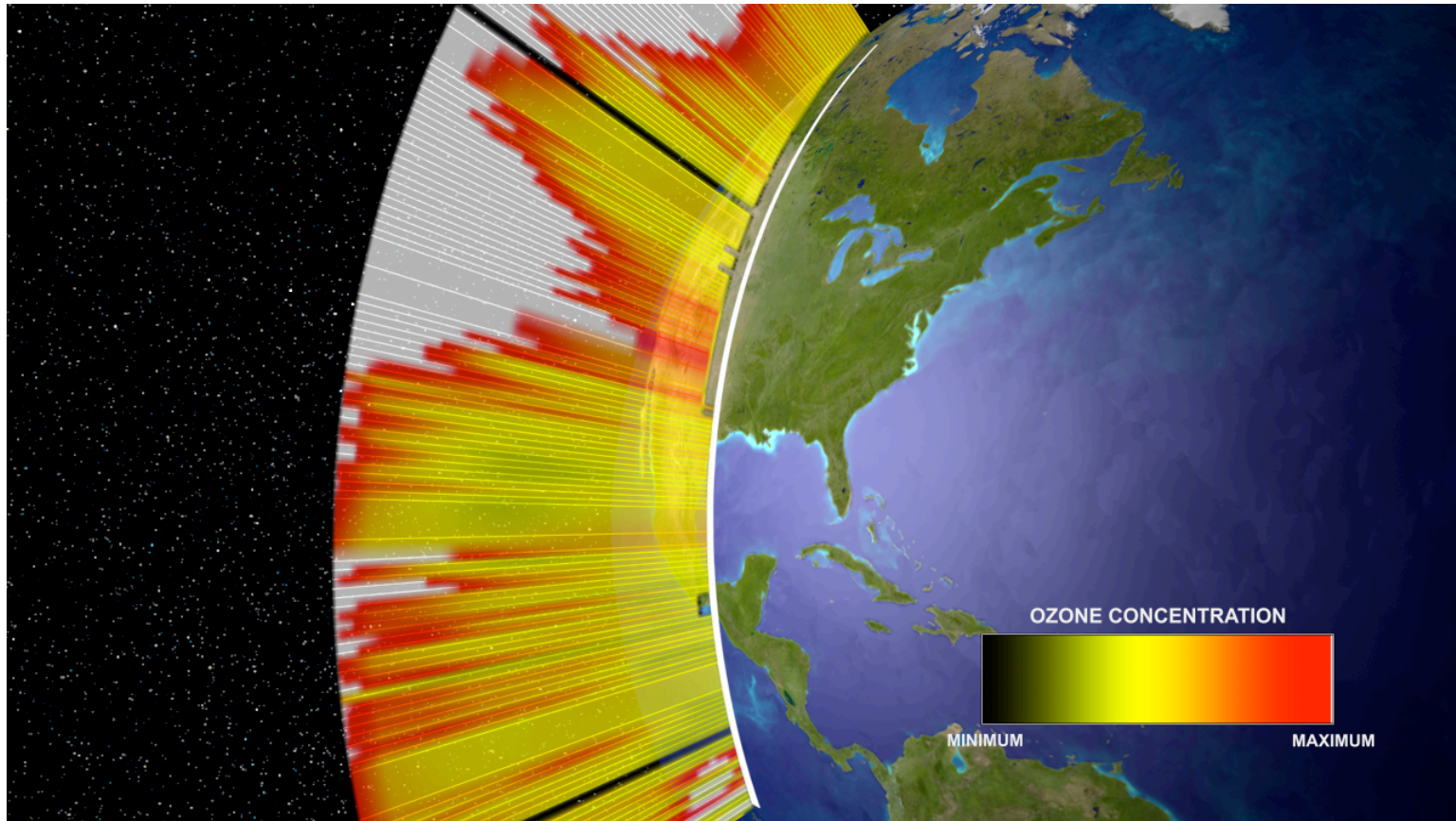




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Insights into tropospheric chemistry: new results utilizing EOS TES

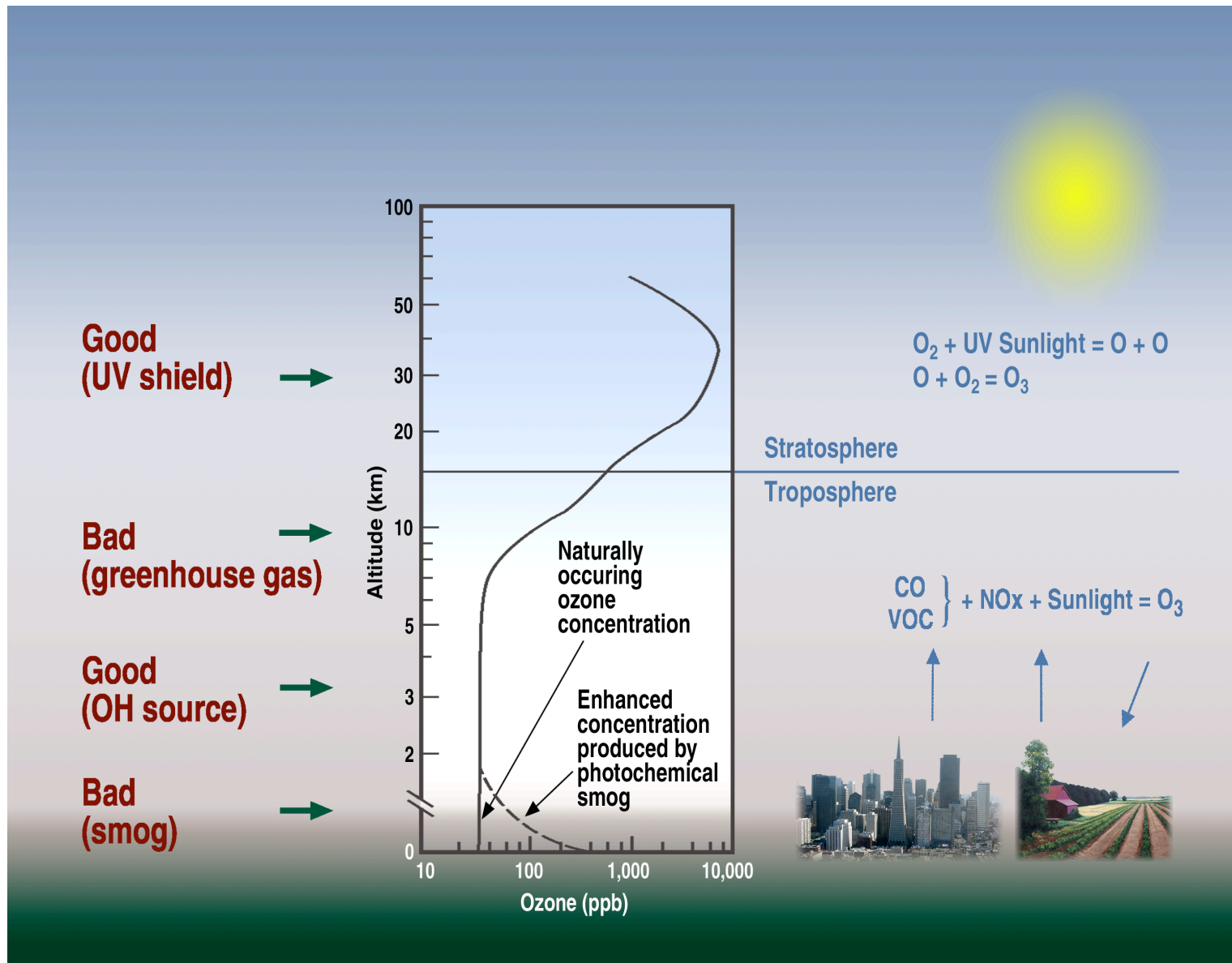


Annmarie Eldering and TES Science Team, JPL/
Caltech



Tropospheric Emission Spectrometer

The vertical distribution of ozone

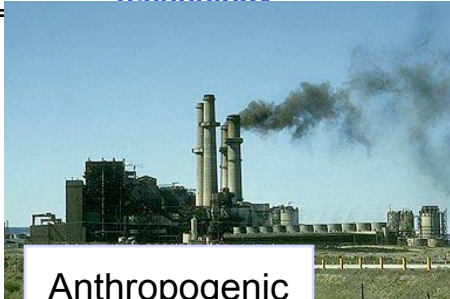




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Tropospheric Emission Spectrometer

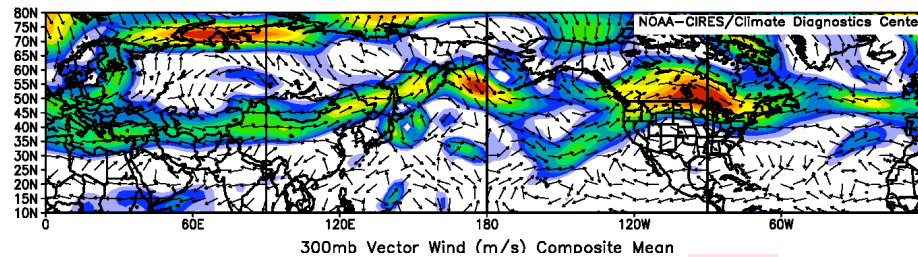
Tropospheric ozone is a complex problem!



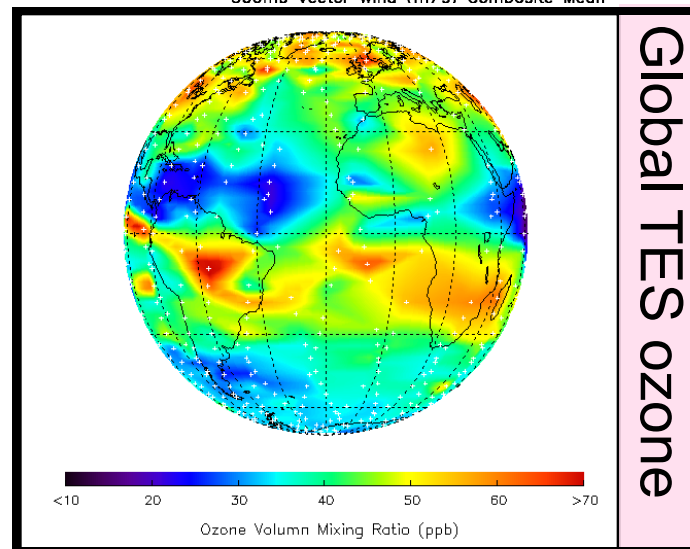
Anthropogenic
sources



Natural precursors



Advection

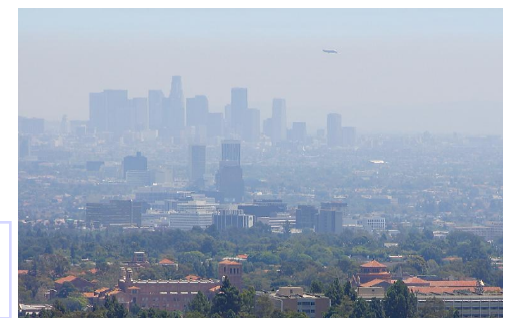


Solar radiation



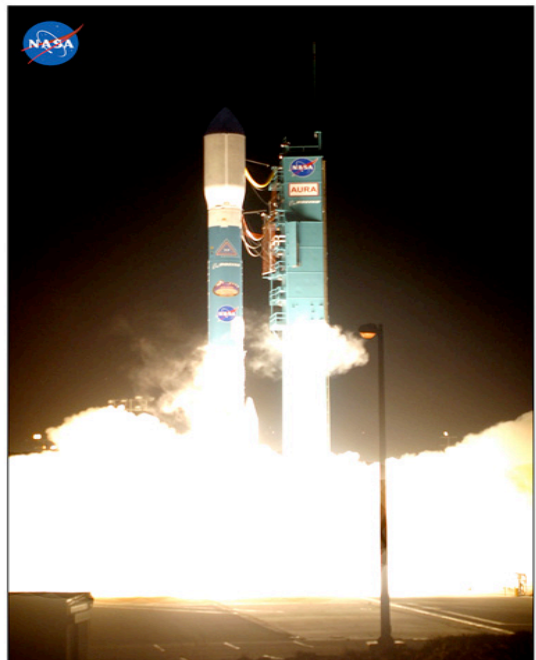
Convection

Subsidence



Tropospheric Emission Spectrometer

TES on EOS-Aura

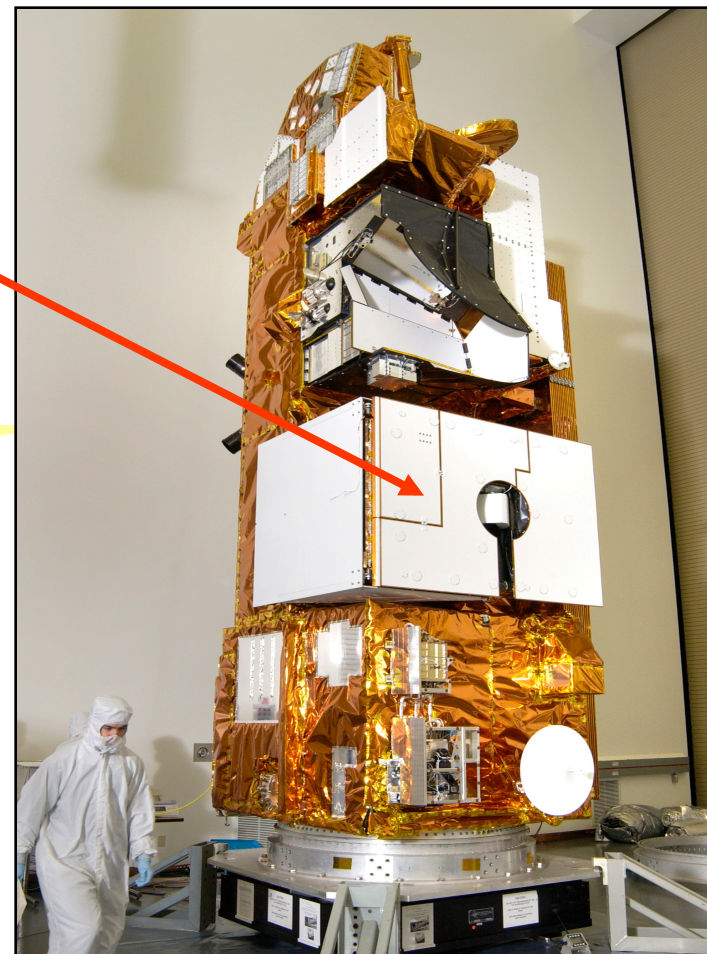


Aura Launch : July 15, 2004
Vandenberg Air Force Base, CA

EOS



Launched 2004.07.15



Goleta Air & Space Museum
www.Air-and-Space.com
©2004, Brian Lockett

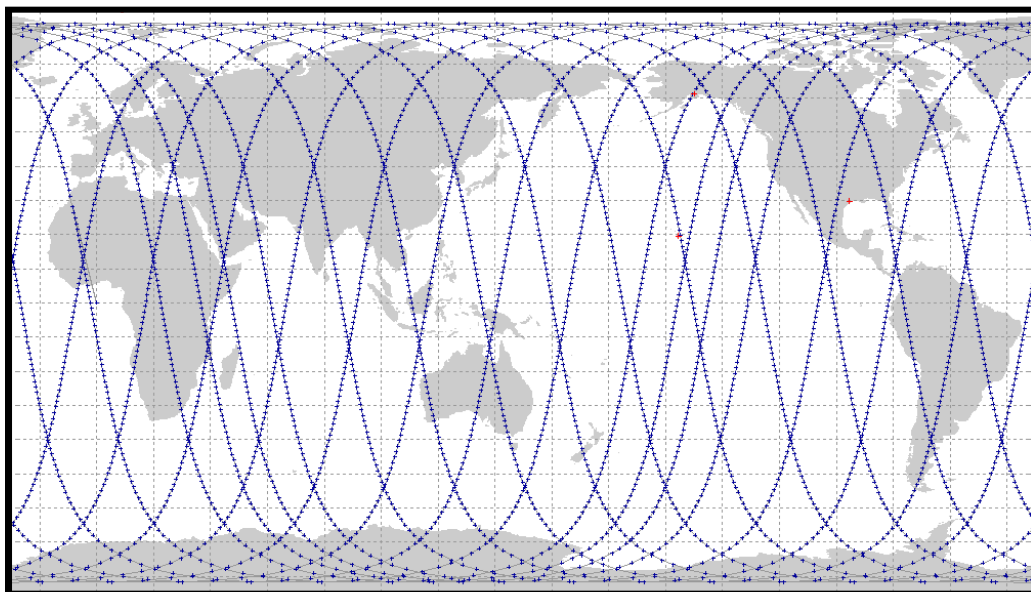




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Tropospheric Emission Spectrometer

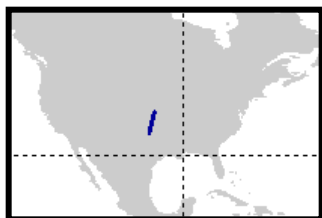
Examples of TES nadir coverage



Global Survey footprints

180 km apart

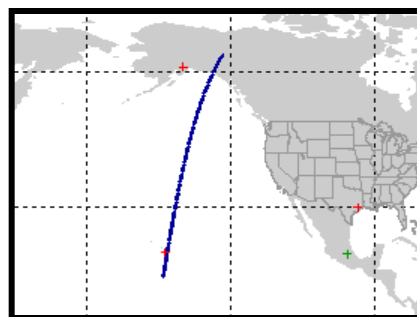
Every 2 days... 600+ and counting



Transect footprints

Contiguous!

Special observation



Step/Stare footprints

45 km apart

Special observation

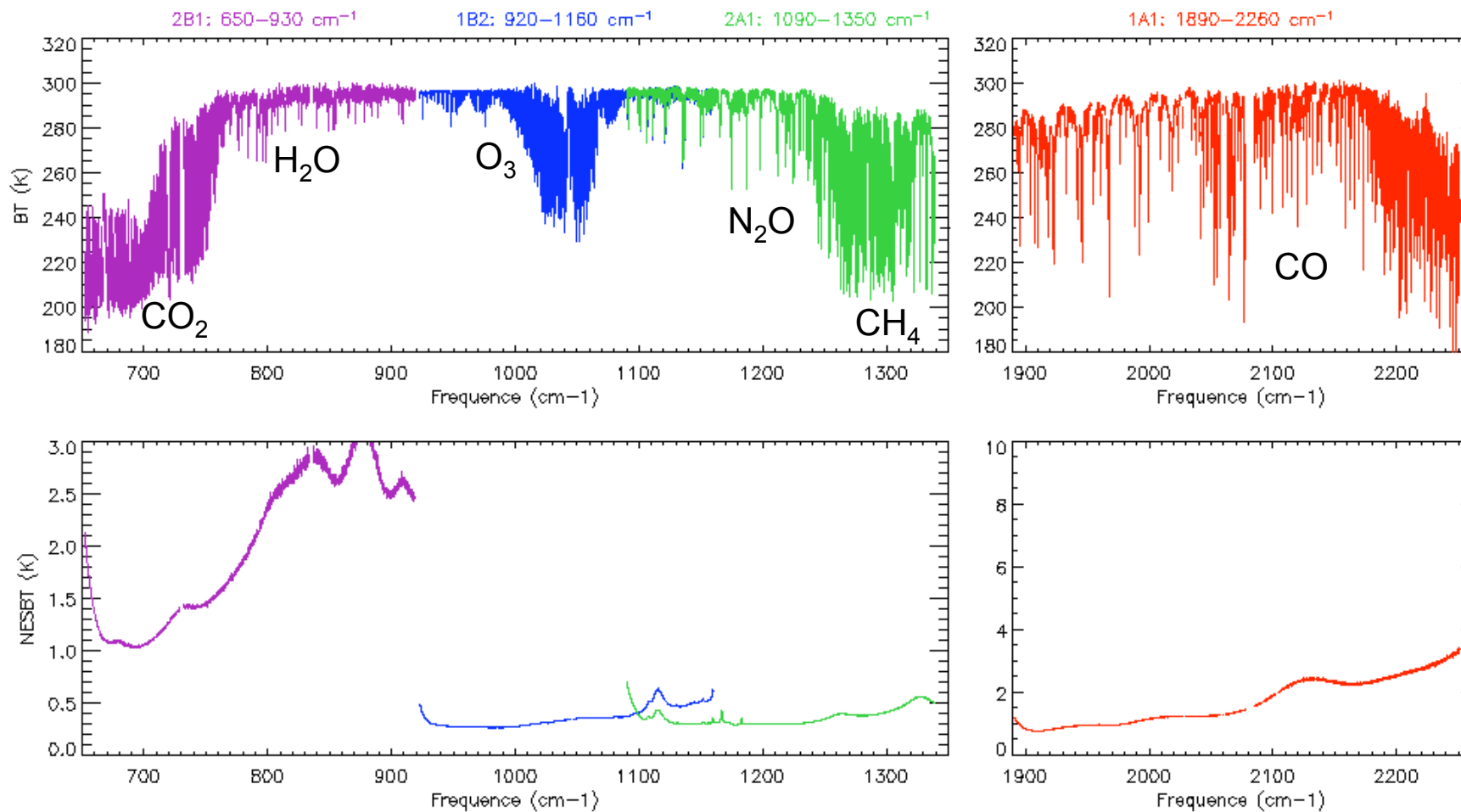


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Tropospheric Emission Spectrometer

TES spectra and noise

Brightness Temperature and Error {K}, Pix-Ave: Run = 3251, Seq = 1, Scan = 72, Lat = 14.3720, Lon = -80.9700, Elev (m) = 0

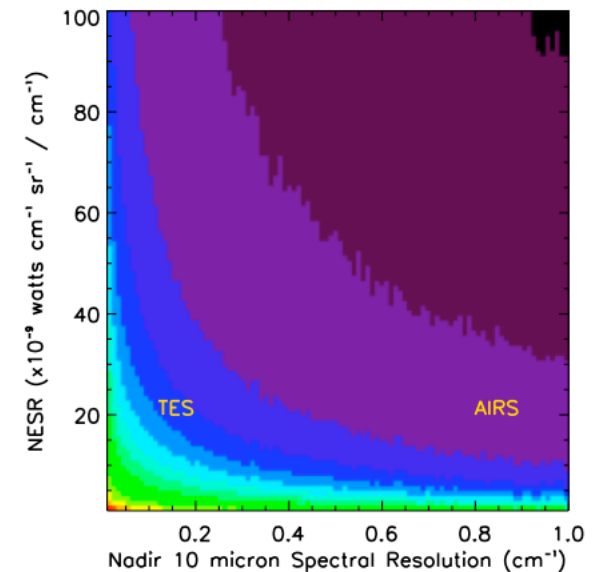
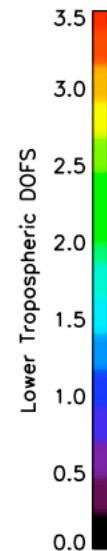
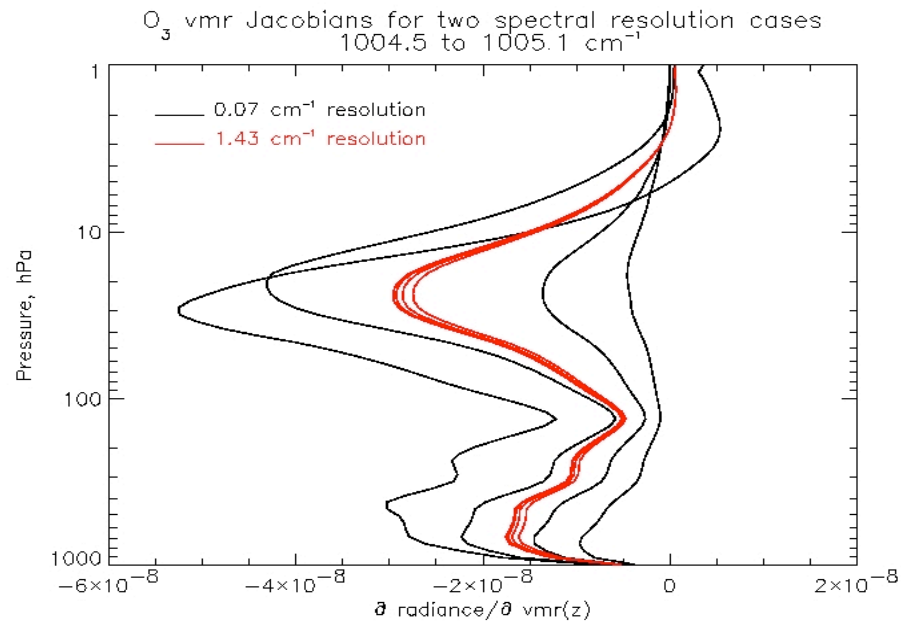
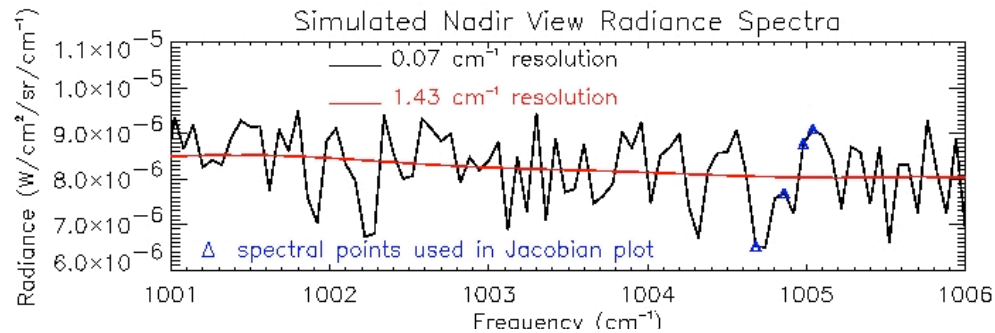




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Tropospheric Emission Spectrometer

It's the spectral resolution!

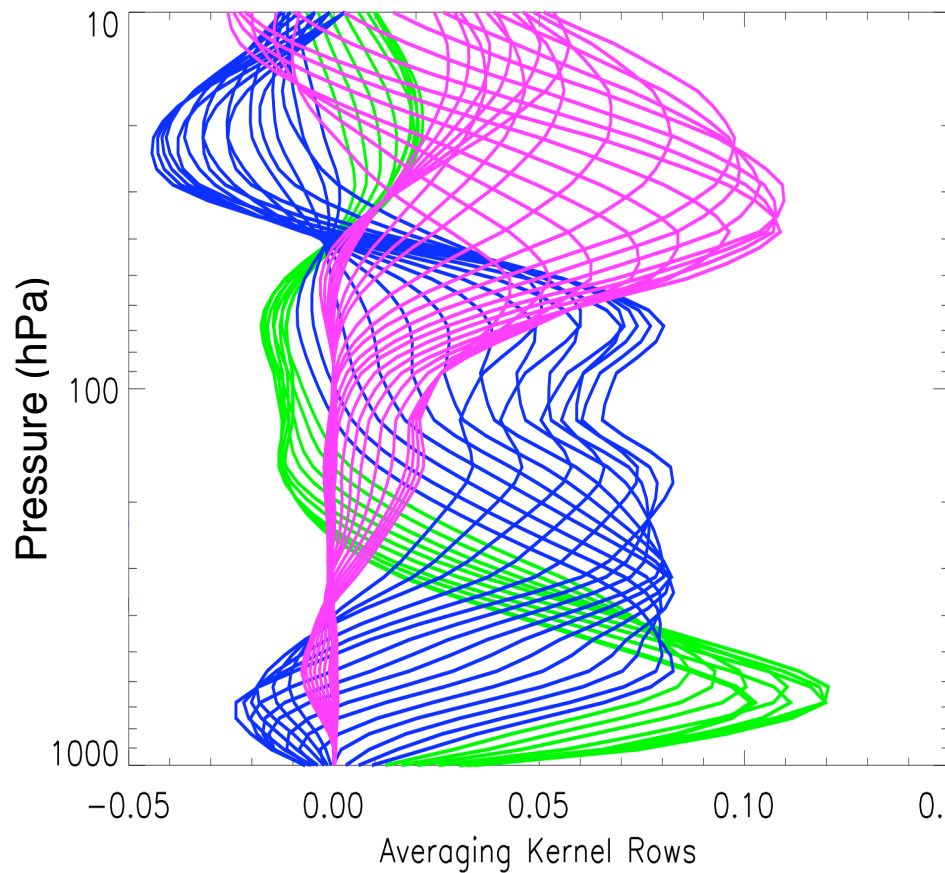




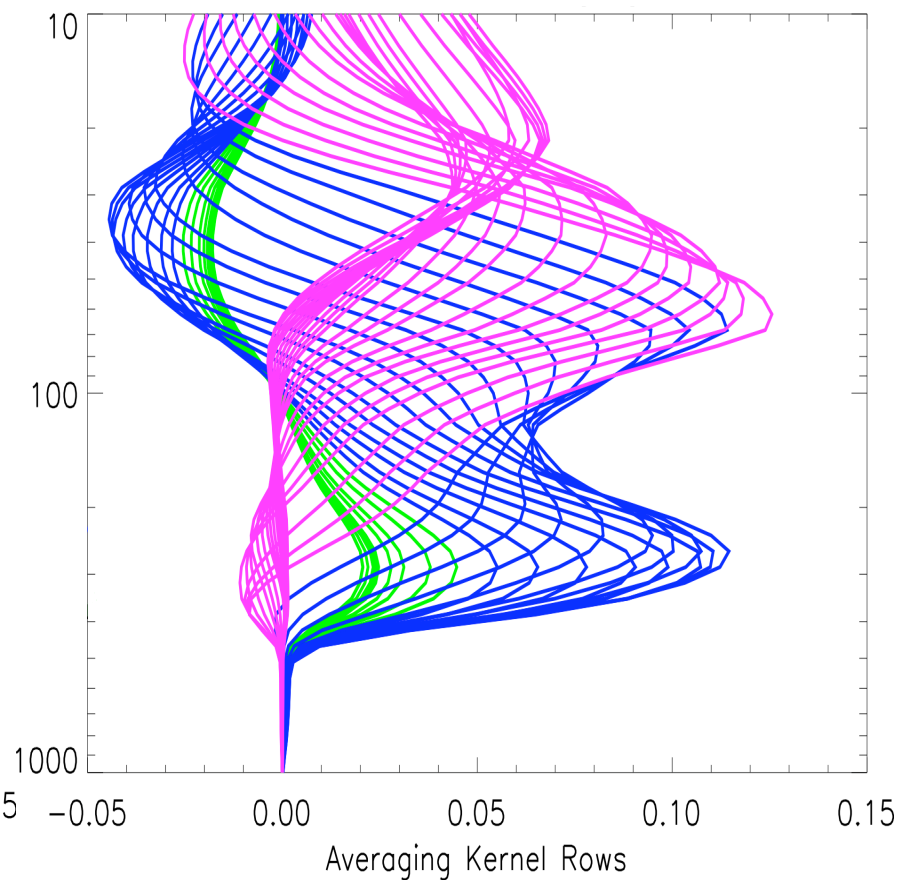
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Tropospheric Emission Spectrometer

Averaging Kernels for Ozone



Clear (DOFS = 4.1)



Cloud at 483 hPa (DOFS = 3.0)



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Tropospheric Emission Spectrometer



Recent TES Findings

- **Global pollution**
- **Local pollution**
- **Climate & dynamics**

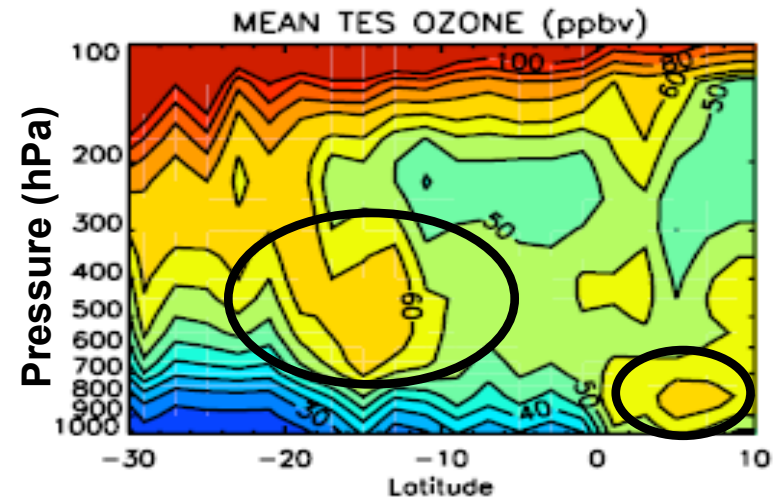
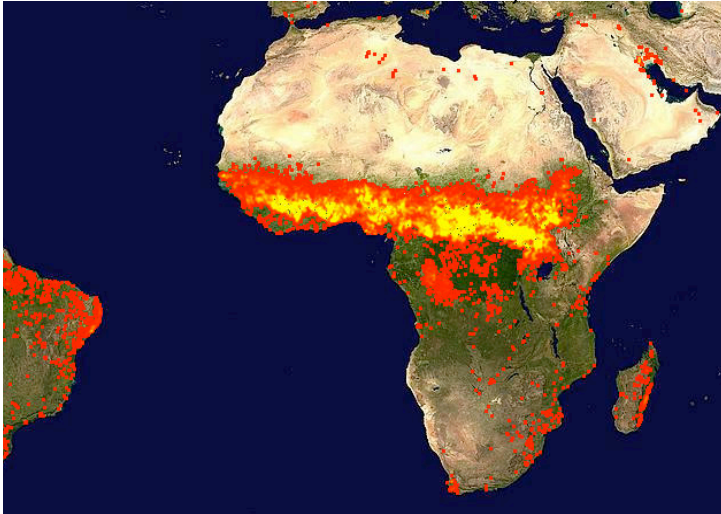


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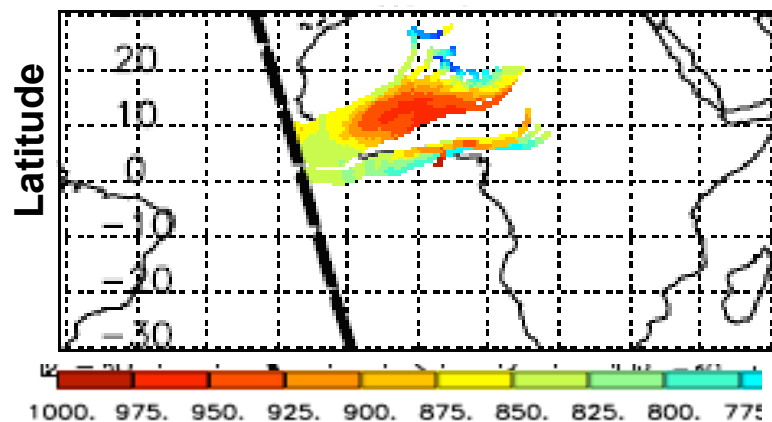
Tropospheric Emission Spectrometer

The tropical Atlantic ozone “paradox”

MODIS firecounts Jan 11-21, 2005



Backward Trajectories from TES



Jourdain (JPL) *et al*, 2007

The tropical Atlantic “paradox” came from TOMS observations of high ozone column South of the ITCZ but low ozone columns North of the ITCZ over Africa during peak biomass burning season (Thompson *et al*, 2000).

With greater sensitivity to the lower troposphere, TES observations show elevated concentrations in the lower troposphere over Africa and in the free troposphere over the tropical Atlantic consistent with in-situ data and model predictions

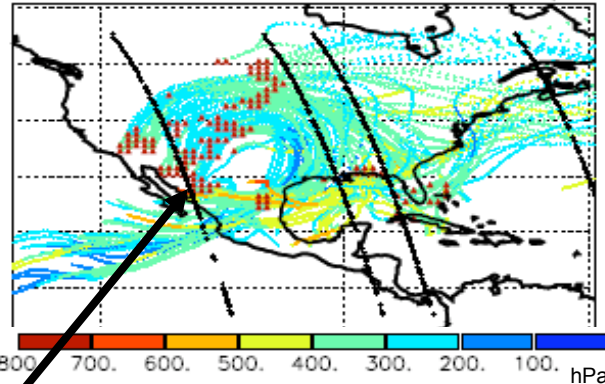


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Tropospheric Emission Spectrometer

Evidence of ozone enhanced layers downwind of lightning events in the USA in summer 2006

Trajectories from NLDN and LRLDN Flashes (subset)

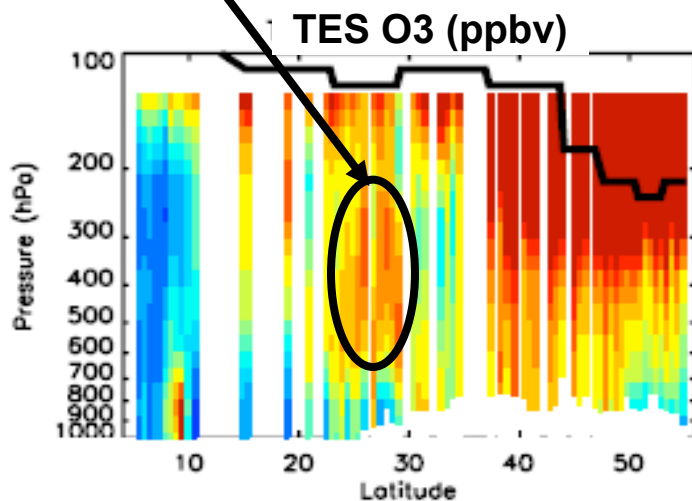


TES locations recently
influenced by lightning

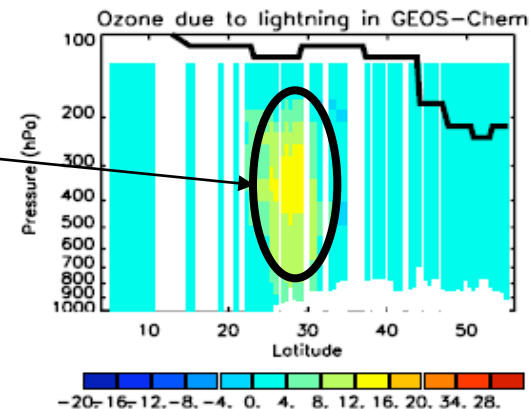
What is the contribution of
lightning to tropospheric ozone?

Approach:

- Initiate trajectories from flashes provided by the lightning distribution networks
- Extract TES ozone observations that intersect trajectories
- Use GEOS-Chem to determine relative contribution of lightning to ozone production



Lightning contributes
to the O₃ enhancement
seen in GEOS-Chem

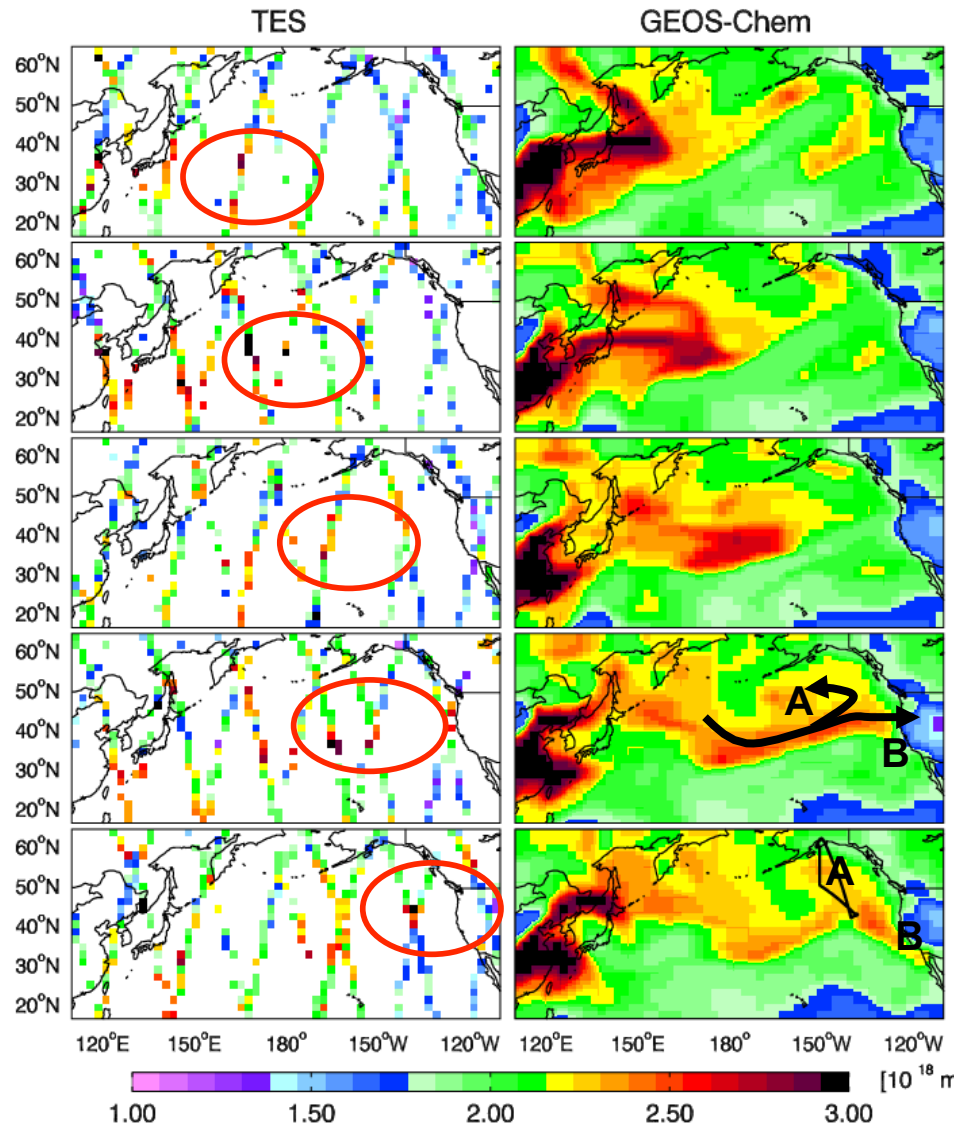


Jourdain et al., in Preparation



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Tropospheric Emission Spectrometer Transpacific transport of Asian pollution to North America



- Asian NO_x emissions have increased by a factor of 2 from 2000-2006.
- Asian anthropogenic emissions contribute 5-7 ppb to the U.S. surface ozone levels in the west.
- The 2000-2006 rise in Asian anthropogenic emissions has led to an increased surface ozone of 1-2 ppbv relative to 2000.
- Transpacific pollution plumes split over the Northeast Pacific

- OMI NO₂ observations used to scale GEOS-Chem emissions
- TES and AIRS CO used to track episodic pollution events
- TES ozone/CO correlations were used to test GEOS-Chem pollution export
- DC-8 and C-130 aircraft observations of PAN, NO_x, CO, and ozone used to examine chemical mechanisms

Zhang (Harvard) et al, in preparation



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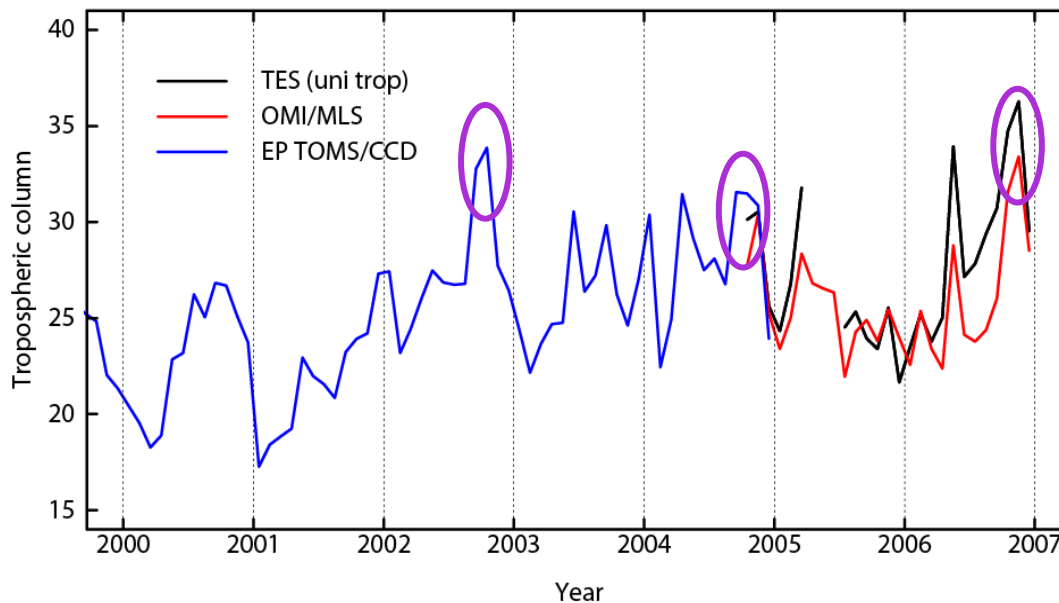
Tropospheric Emission Spectrometer

Record of ozone and El Ninos

**Trop. ozone columns from TES, OMI/MLS,
and EP-TOMS (CCD method)**

Highest ozone in Sept.-Nov. in 2006, 2002, 2004.

Indonesia (5N-10S, 70-120E)



**EP-TOMS and OMI/MLS results
from Chandra and Ziemke**

- Impact of El Nino on tropospheric column ozone has been seen from earlier measurements

- Which layers of the troposphere are most impacted?

- Can we assemble the large scale picture of chemistry and dynamics?

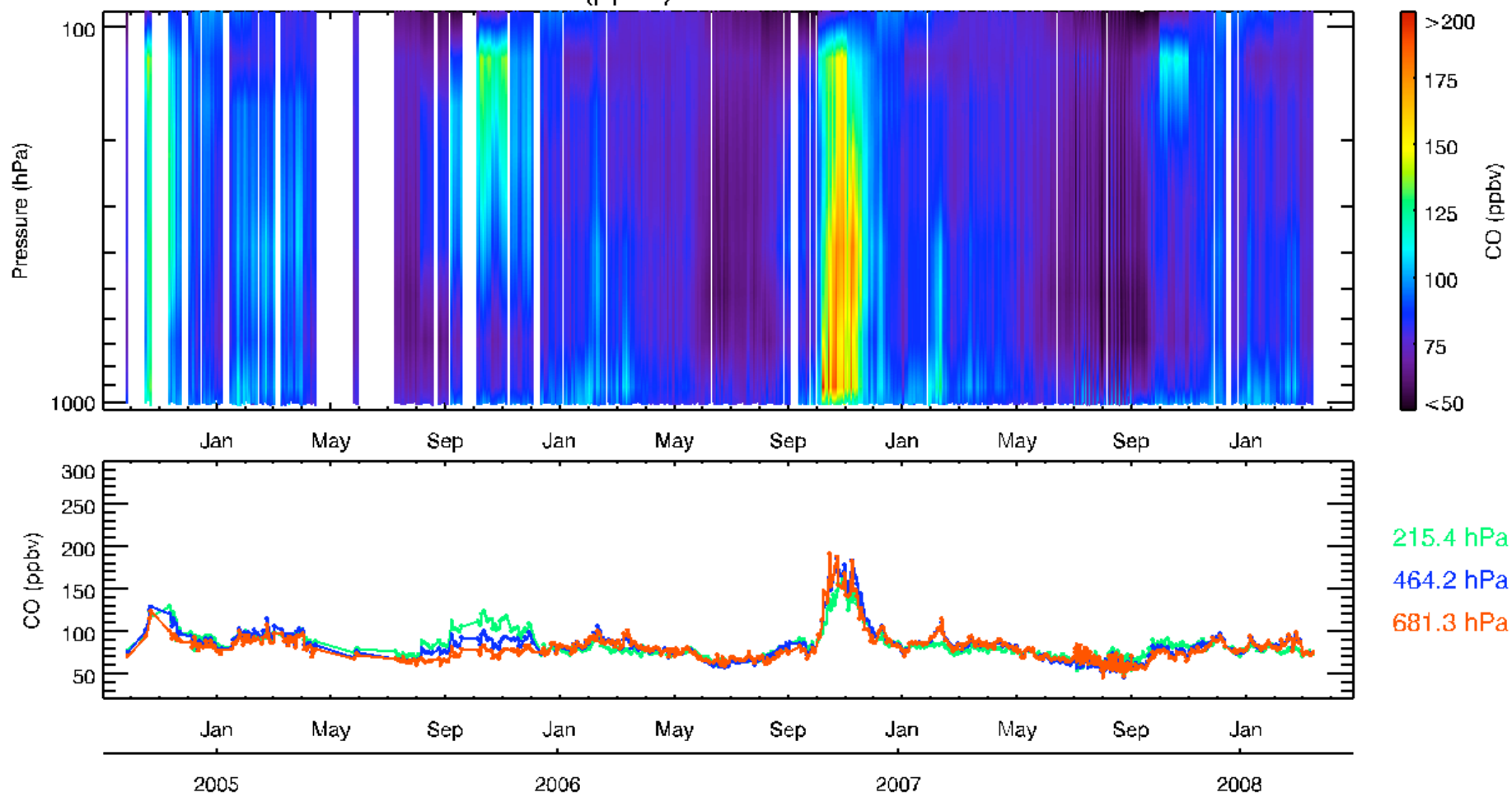


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Tropospheric Emission Spectrometer

Vertically resolved record of CO

TES CO (ppbv) Time Trend: Indonesia



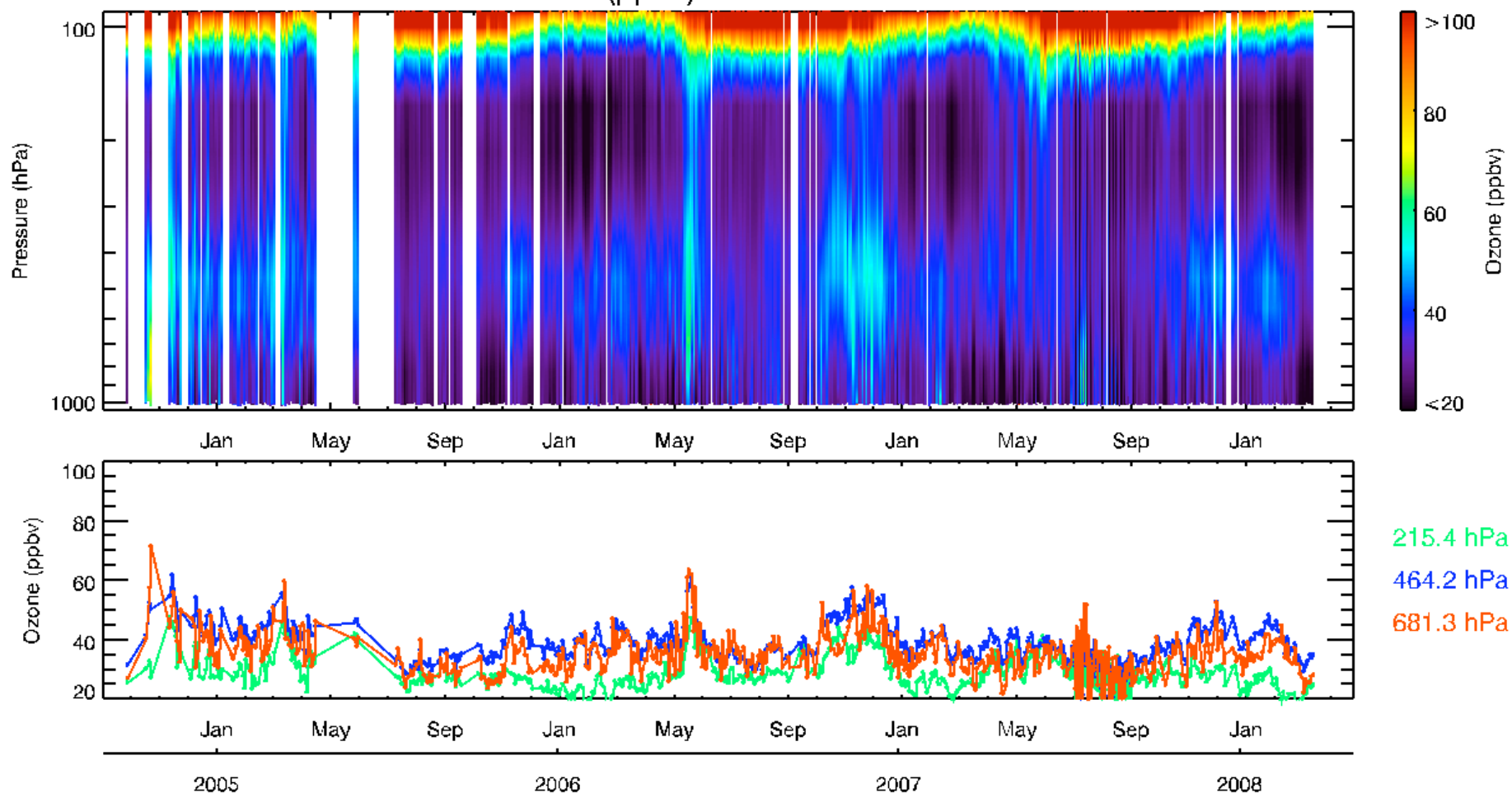


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Tropospheric Emission Spectrometer

Vertically resolved record of O₃

TES Ozone (ppbv) Time Trend: Indonesia

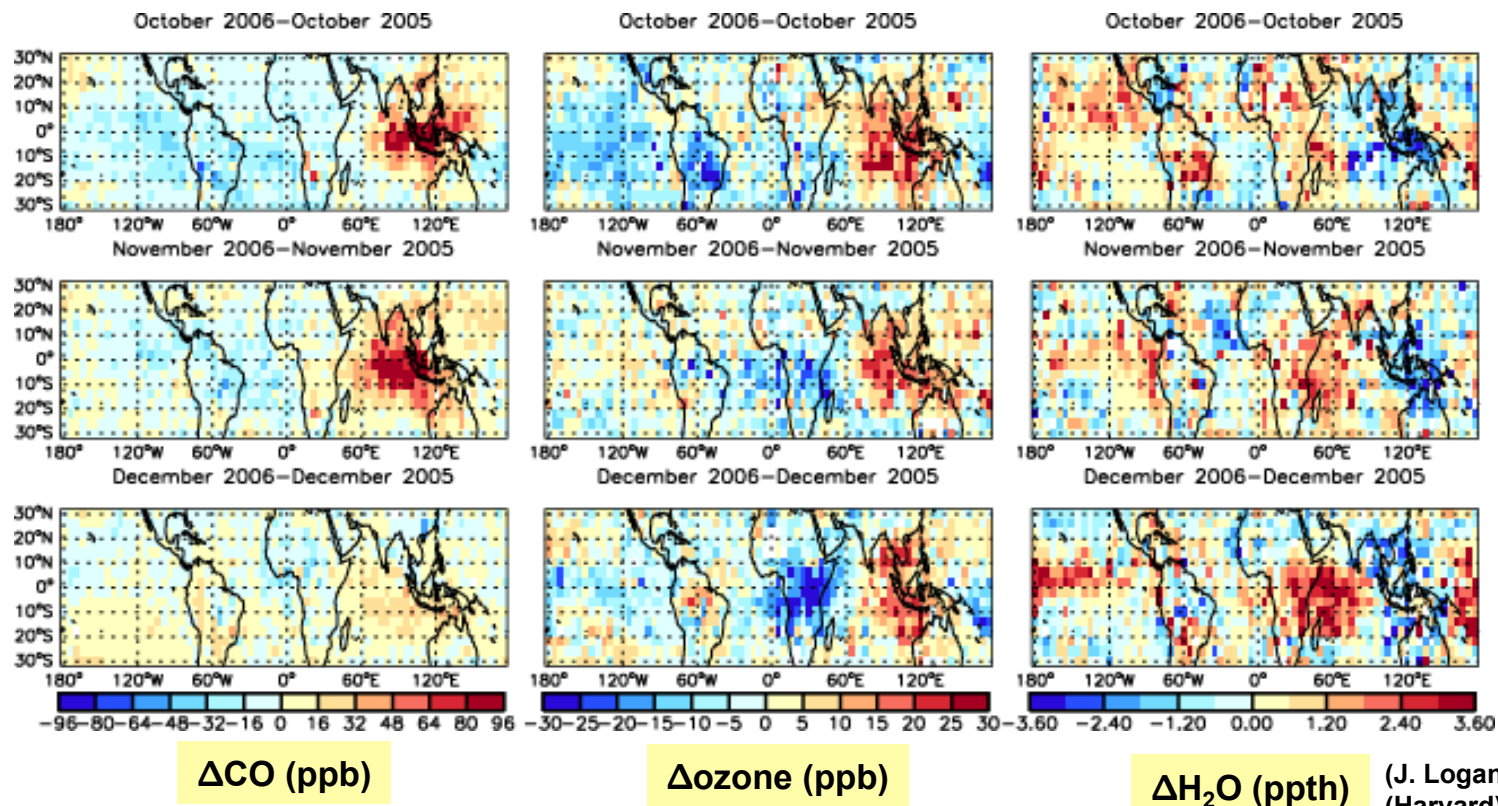




Tropospheric Emission Spectrometer

El Niño impact on O₃ and CO

- Drought in Indonesia from the 2006 El Niño caused major fires.
- Decreased water vapor over Indonesia (right) results from convection shifting to the Pacific during El Niño.
- CO from the fires (left) and shifts in convection both contribute to elevated ozone over Indonesia (center).



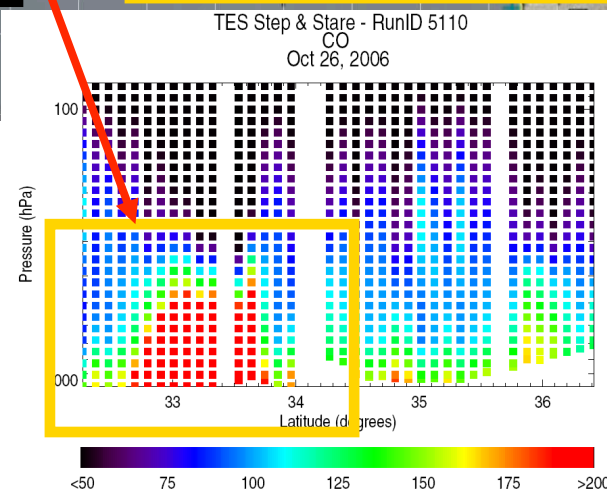
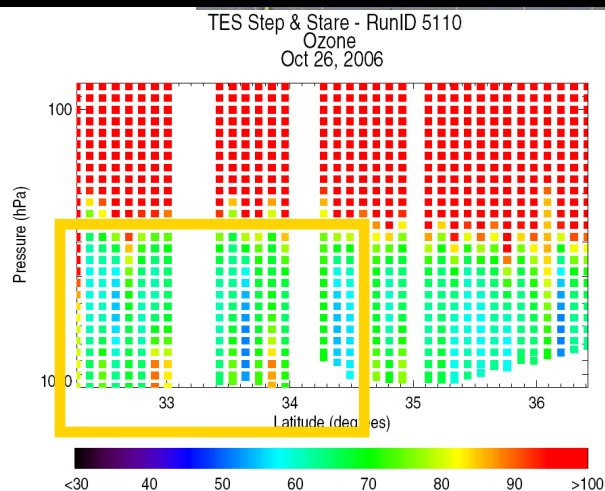
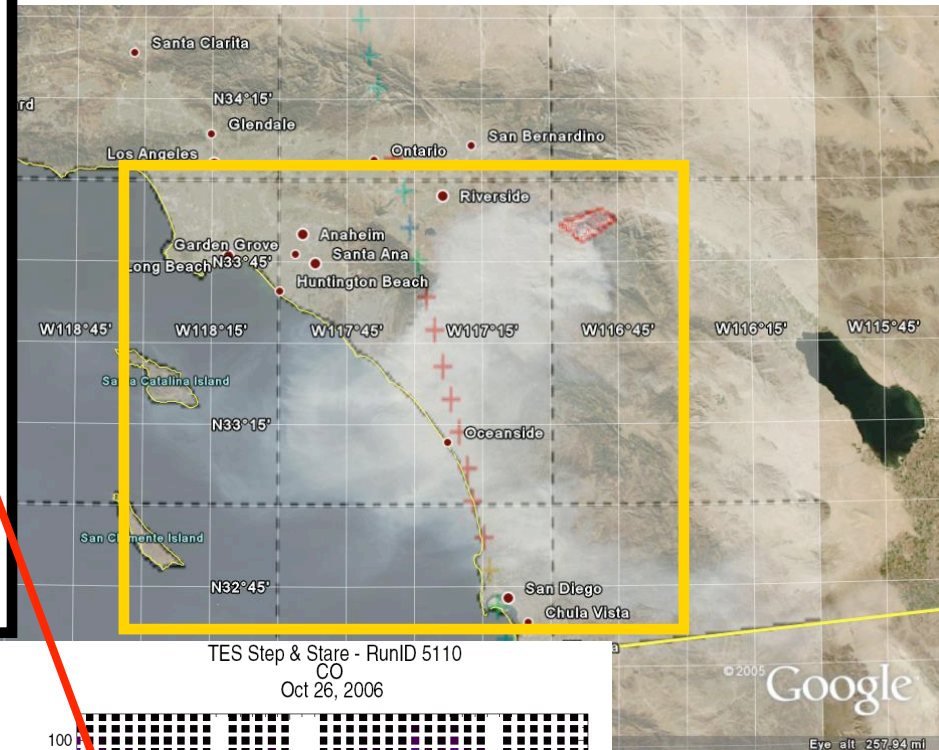


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Tropospheric Emission Spectrometer

October 26, 2006 – California Wildfire

- Examination of the effect of the Esperanza Fire on tropospheric ozone using TES and other satellite instruments
- TES measures the vertical profiles of ozone and carbon monoxide down wind of the plume (**Very large plume of CO**)
- Also use OMI, MLS, AIRS and surface monitor data to understand the evolution of ozone in the plume and possible air quality implications



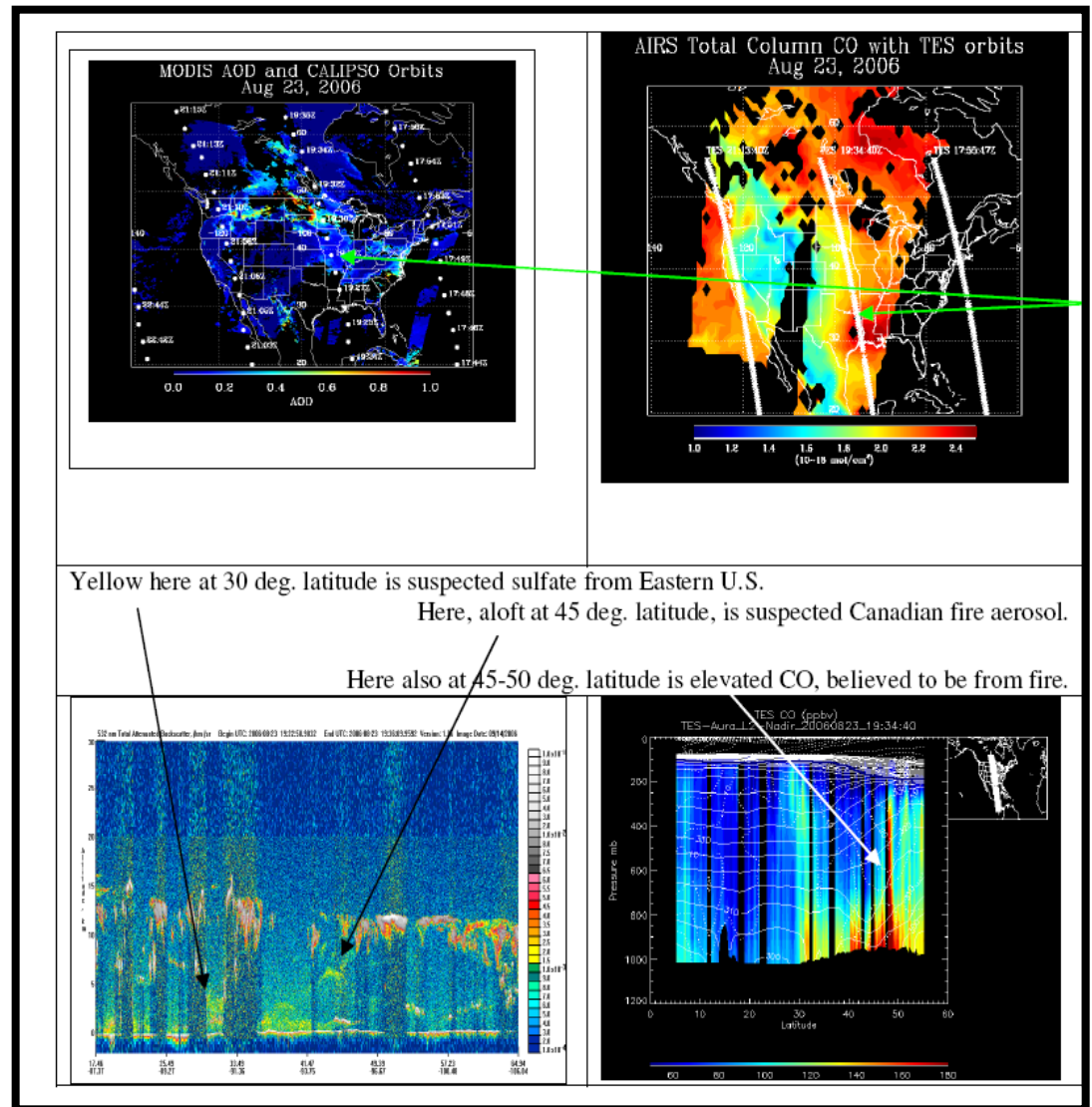
G Osterman et al., 2008 (in prep)



Tropospheric Emission Spectrometer

Houston, Texas Air Quality

- Regional ozone production preceded 6 of 9 days with high surface values in Houston
- Source Regions for Houston
 - Midwest/Ohio River
 - Chicago
- Regional ozone production preceded 7 of 15 days with high surface values in Dallas
- Source regions for Dallas:
 - Great Lakes/Southern Canada
 - Midwest/Ohio River

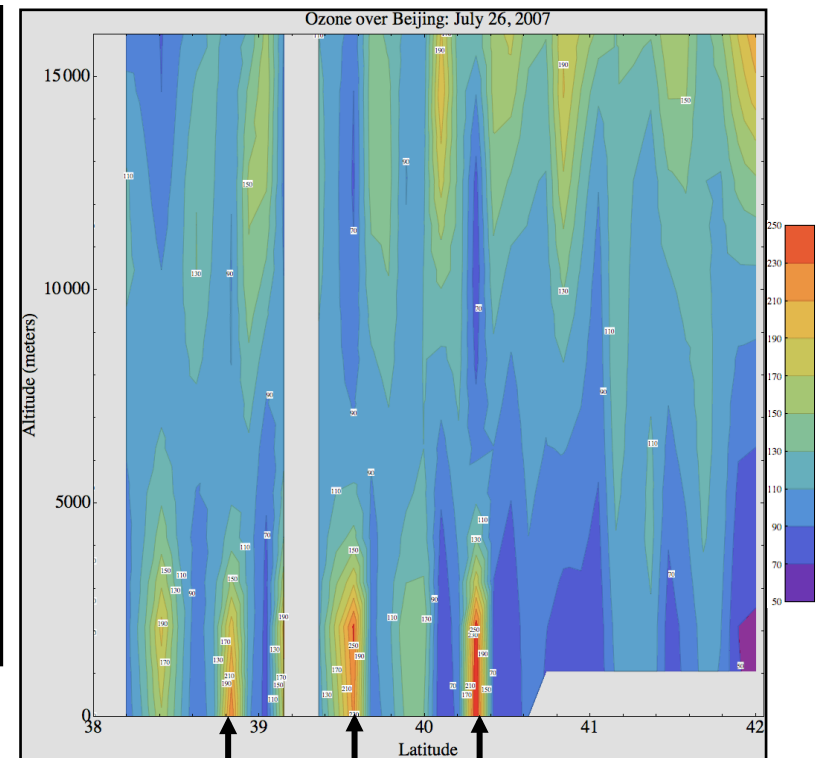
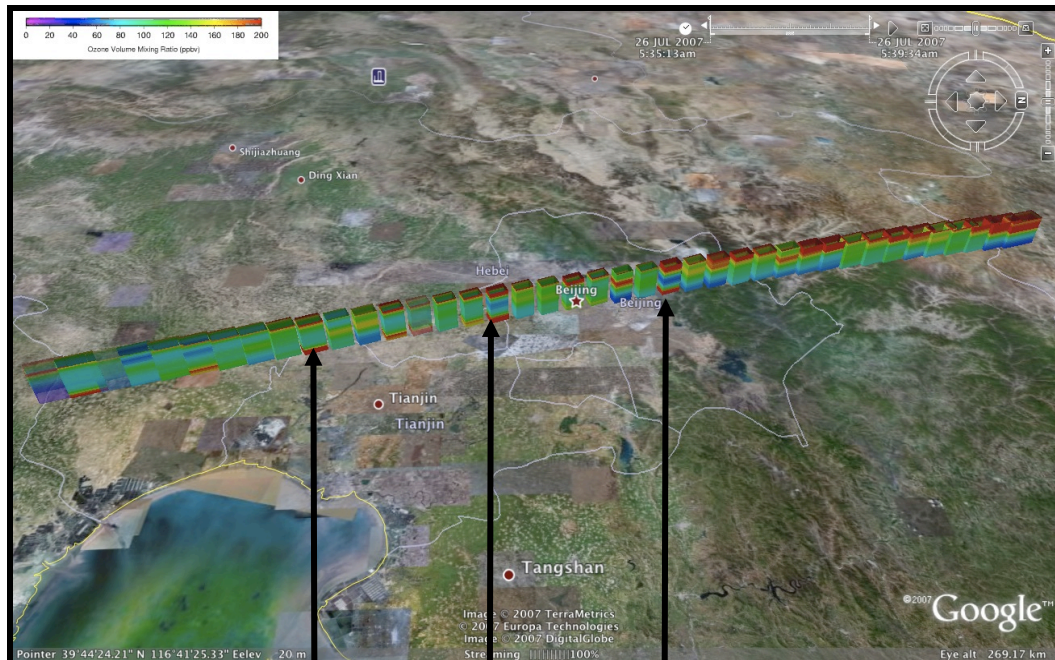




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Tropospheric Emission Spectrometer

TES Ozone over Beijing, July 26, 2007



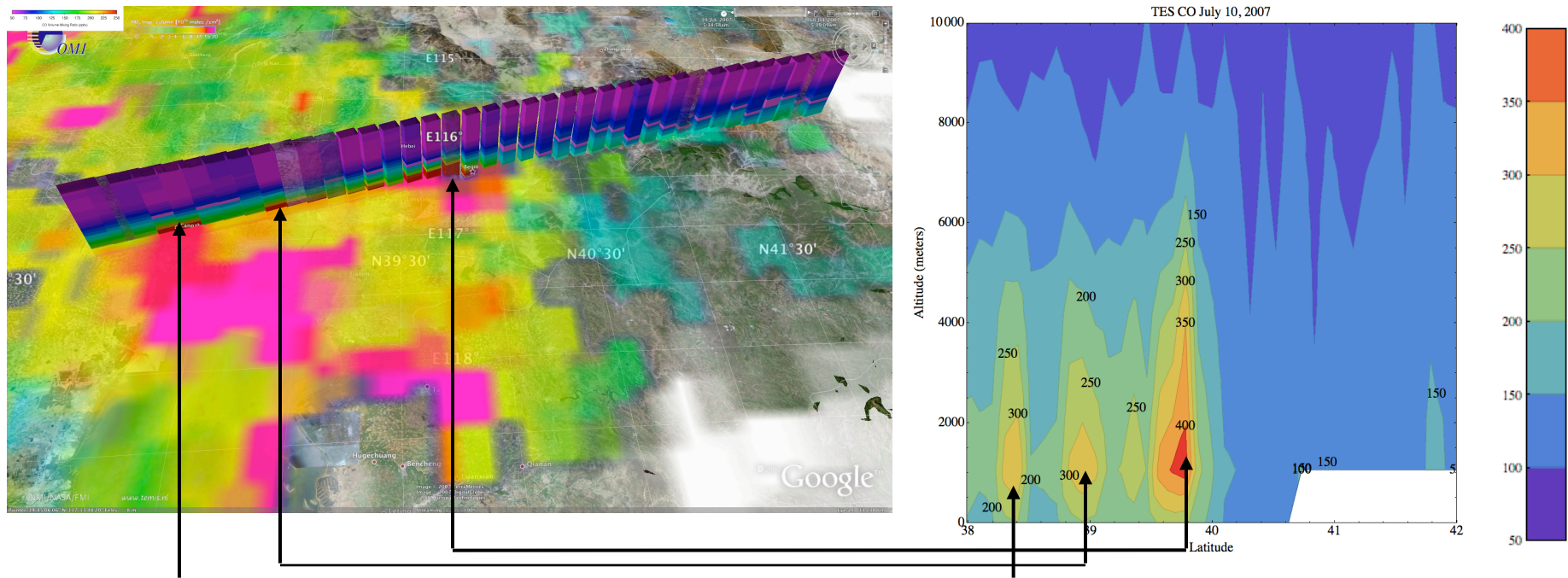
- TES “transect” over Beijing, China, July 26, 2007 (North is to the right). Right panel is the vertical distribution of ozone.
- TES ozone observations taken on July 26, 2007 show 3 observations exceeding 200 ppb at 825 hPa



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Tropospheric Emission Spectrometer

TES CO and OMI NO₂ over Beijing July 10th, 2007



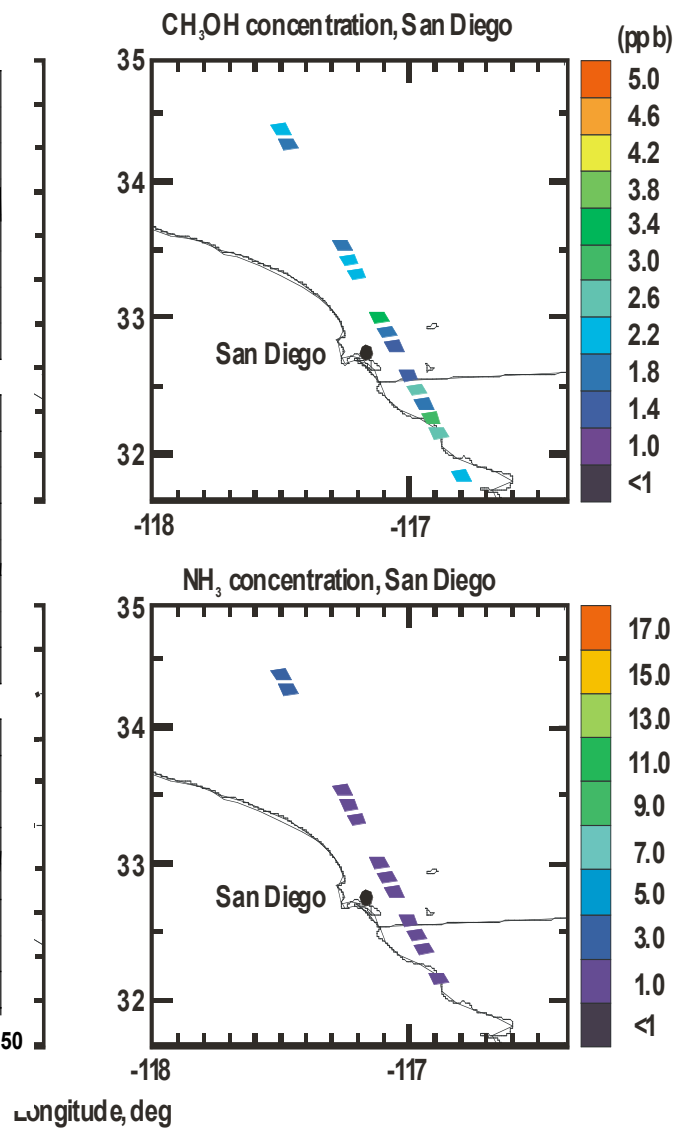
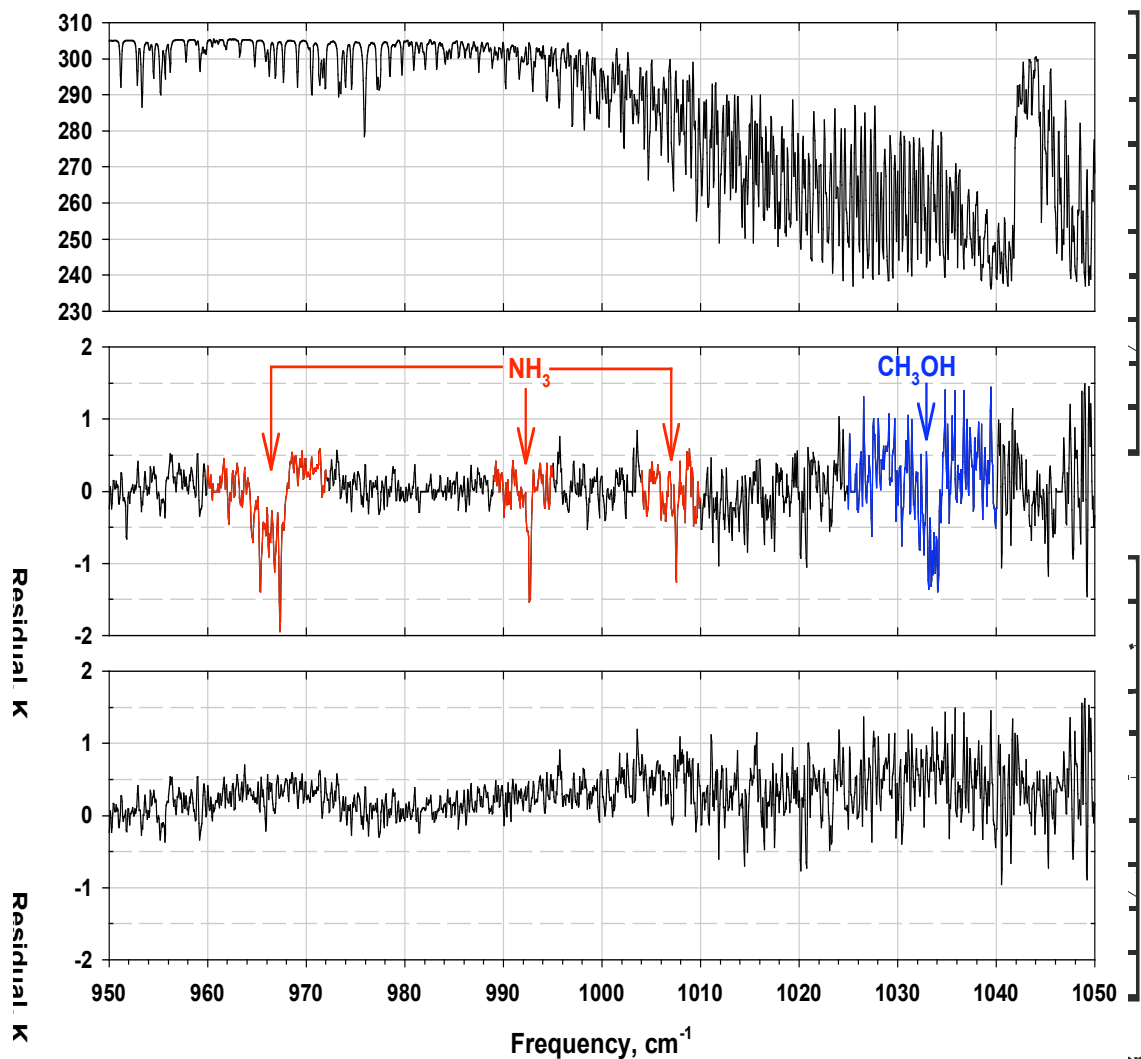
Elevated TES CO (> 300 ppb) are spatially coincident with OMI Tropospheric NO₂ concentrations



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Tropospheric Emission Spectrometer

Retrievals of Ammonia and Methanol

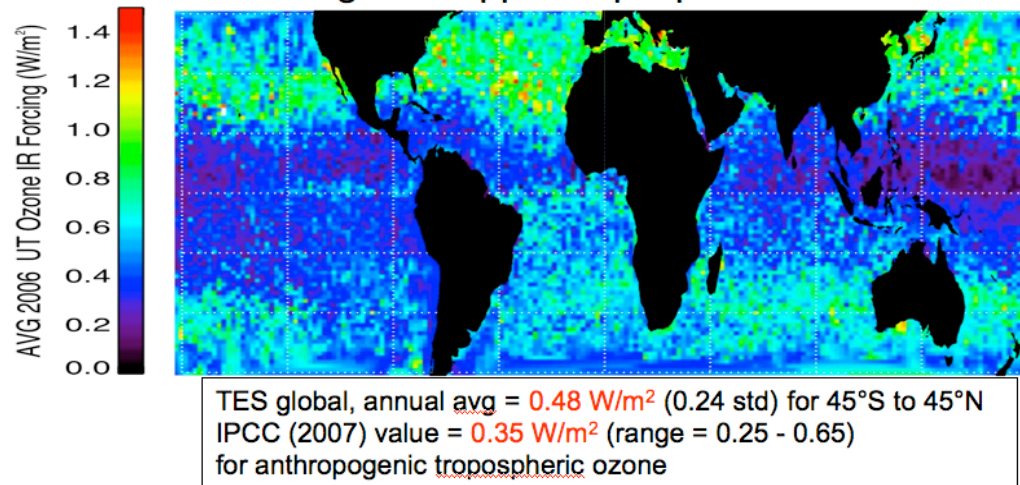




Tropospheric Emission Spectrometer

Radiative forcing due to tropospheric ozone

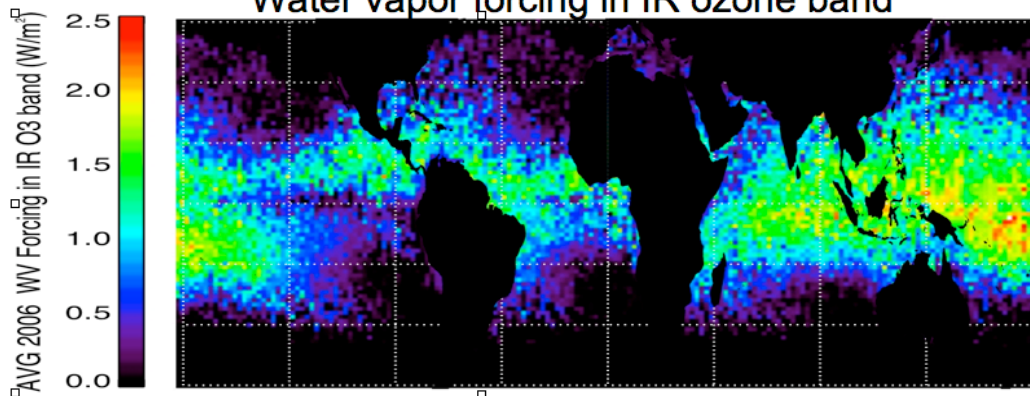
IR forcing from upper tropospheric ozone



Problem: Radiative forcing of tropospheric ozone is modeled, but not measured. Tropospheric ozone is important in total radiative budget and uncertain in the future.

Result: TES observations used to quantify the observed IR forcing of tropospheric ozone and water vapor in the ozone band.

Water vapor forcing in IR ozone band



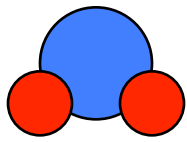
Significance: First space-borne measurement of tropospheric ozone forcing. TES observations are in the range of model forecasts, but show more sensitivity of IR forcing in the Northern Hemisphere than models.



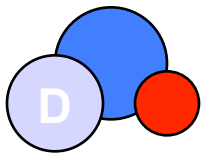
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Tropospheric Emission Spectrometer

Importance of rain evaporation and continental convection in the tropical water cycle



H₂O



HDO

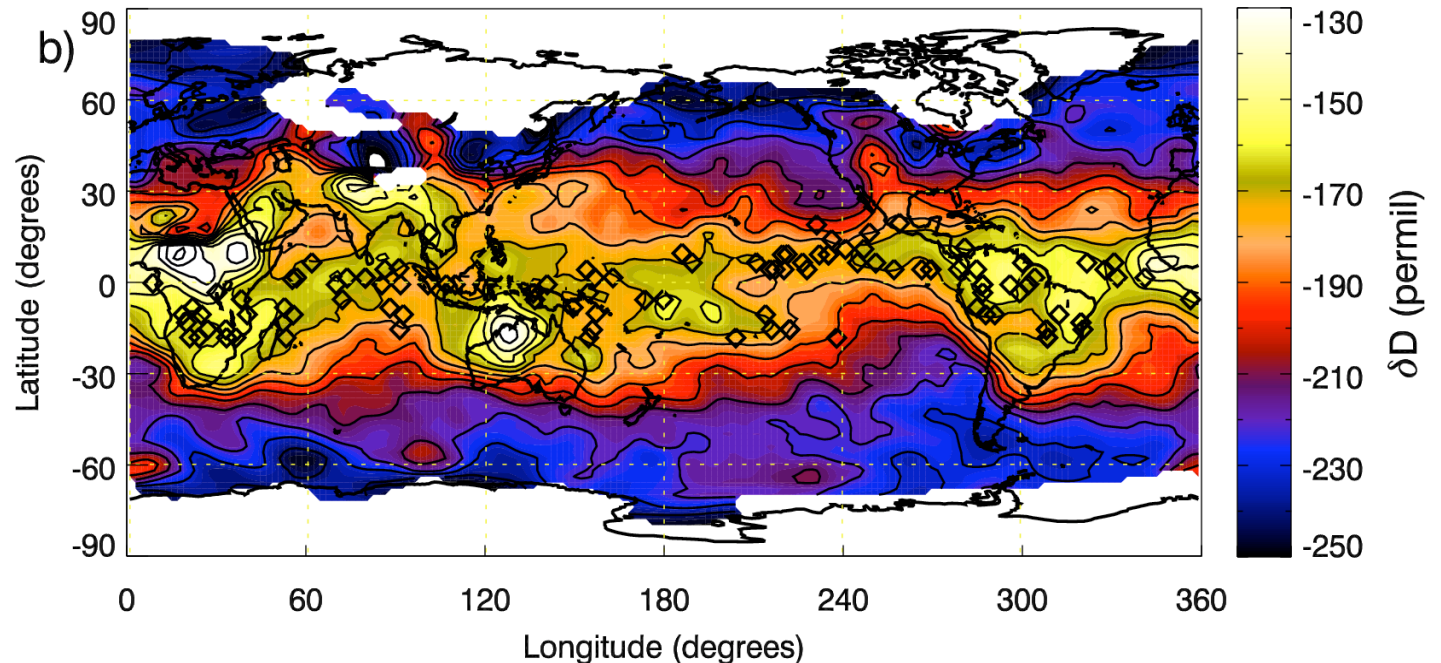
TES HDO

(~700 hPa)

50 days

Oct 05 –

Mar 06)



Water isotopes identify and quantify “hidden” water sources

Rainfall evaporation an important rehydration mechanism in tropics

Direct observation of evapo-transpiration as a tropical water source

J. Worden, D. Noone, K. Bowman, *et al.*, *Nature* 445, 528 - 532 (01 Feb 2007)



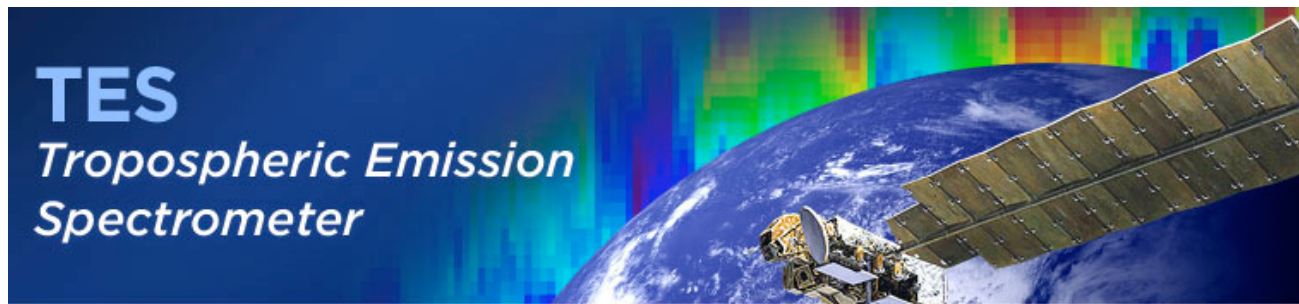
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Tropospheric Emission Spectrometer

Conclusions

- TES is providing unprecedented vertically resolved chemical observations of the Earth's lower atmosphere.
- Over 4(!) years of measurements, processed consistently, with validated products are available.
 - For details and links to data go to:

<http://tes.jpl.nasa.gov>





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Tropospheric Emission Spectrometer



For more info and links to data centers:

tes.jpl.nasa.gov

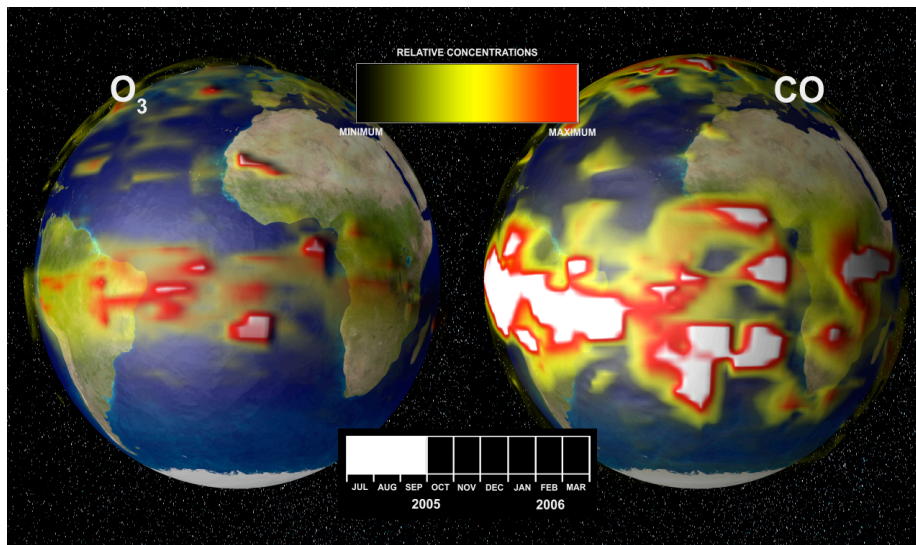


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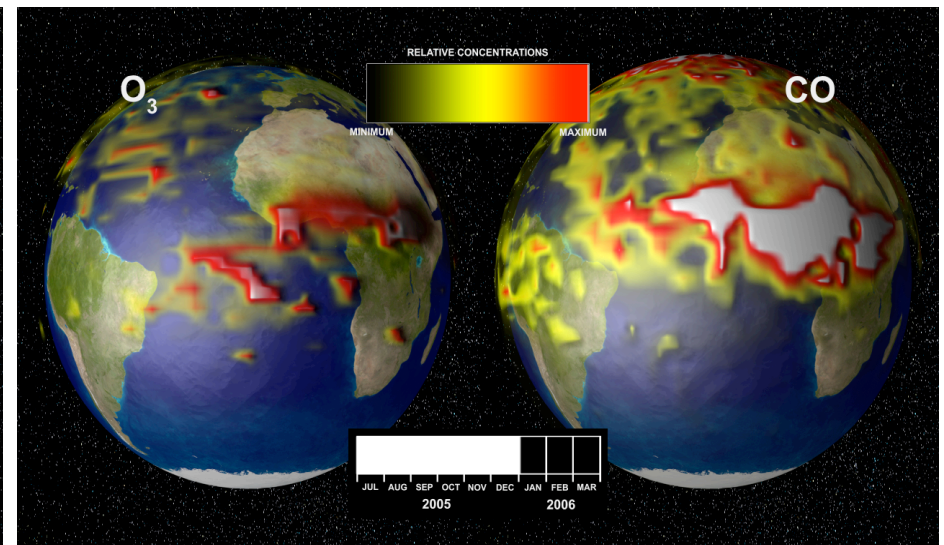
Tropospheric Emission Spectrometer

Global Views of Ozone and Carbon Monoxide from TES

Lower troposphere (750 hPa, about 2.4 km)



Signatures of southern hemisphere
spring biomass burning.
September 2005.

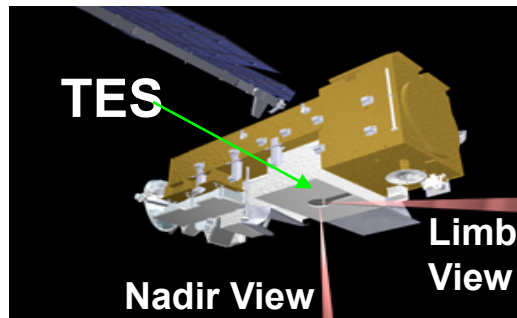


Signatures of Northern Africa
winter biomass burning.
Dec 2005, Jan 2006.



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TES Instrument Specifications



<http://tes.jpl.nasa.gov>



Tropospheric Emission Spectrometer

Spectrometer Type	Connes'-type 4-port Fourier Transform Spectrometer
Max. Optical Path Difference	± 8.45 cm (normal) ± 33.8 cm (hi-res); interchangeable
Scan (integration) Time	4 sec (normal) 16 sec (hi-res)
Sampling Metrology	Nd:YAG laser
Spectral Resolution (unapodized)	0.06 cm^{-1} (normal) 0.015 cm^{-1} (hi-res)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 um)
Detector Arrays	4 (1 x 16) arrays, optically- conjugated, all MCT PV @65K
Field of Regard	45° cone about nadir; trailing limb or cold space; internal calibration sources
Pointing Accuracy	75 urad pitch, 750 urad yaw 1100 urad roll
Max. Stare Time,	208 sec (40 nadir scans)
Spatial Resolution	$0.5 \times 5 \text{ km}$ (nadir) $2.3 \times 23 \text{ km}$ (limb)
Radiometric Calibration	cavity blackbody (340K) + cold space view
Detector Array Co- alignment	Internal thin slit calibration source
Nadir NESR (Noise Equivalent Spectral Radiance)	2B1 filter: $700 \text{ nW/cm}^2/\text{sr/cm}^{-1}$ 1B2 filter: 200 2A1 filter: 150 1A1 filter: 100
Nadir NEDT @290K (Noise Equivalent Delta Temperature)	2B1: 1.08 K for 16 detector average 1B2: 0.36 K for 16 detector average 2A1: 0.36 K for 16 detector average 1A1: 2.07 K for 15 detector average

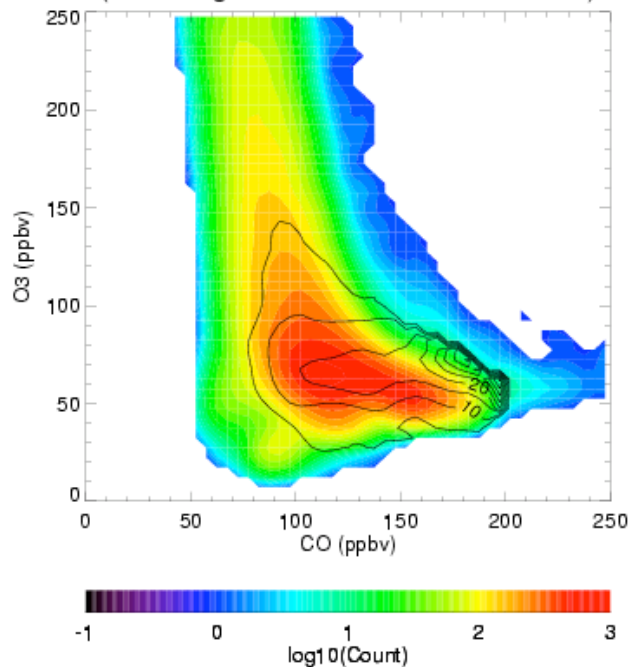


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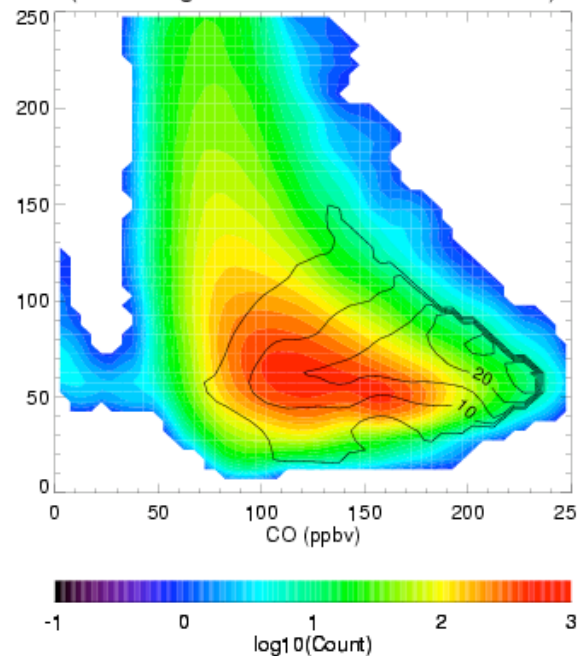
Tropospheric Emission Spectrometer Influence of Southeast Asian fires over the Pacific

Influence of fires from CO/ozone distributions observed by TES and predicted by RAQMS

RAQMS retrieved Pacific Tropospheric CO vs O3 PDF April 2006
(Percentage Wildfire influences Contoured)



TES Pacific Tropospheric CO vs O3 PDF April 2006
(Percentage Wildfire influences Contoured)



Left: RAQMS predicted probability distribution of CO and ozone April 2006 at TES sampling.
Right: Observed TES probability distribution of CO and ozone
Contours are percentage influence from biomass burning

- 20% of elevated CO (> 180ppb) observed by TES over the Pacific is associated with wildfire emissions, consistent with expected RAQMS distribution
- Few ozone enhancements (>100 ppb) are associated with these fires.
- Discrepancies between RAQMS and TES attributed to meridional background of CO in RAQMS and co-location of plumes in clouds

Bowman, Pierce, et al.



Material to add

- Yunsoo's results – regional models
 - Sunita and boreal fires
 - Sunita - tibetian plateau
 - Anything from Changsub
 - Methane from viviene
-
- Eventually – susan CO₂, Dylan/parrington, does Kevin have his own co-authored papers??
 - Anything from the field campaigns like ARCTAS, was there a strong results from INTEx